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Surface Temperature Gradients As Indicators of the Position of the Gulf Stream

by

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This paper is an investigation of the possibility of determing the position of the Gulf Stream from an examination of surface temperature gradients. As considered here, the Gulf Stream is the band of water between Cape Hatteras and 50°W. where the temperatures change abruptly at all depths down to 2000 m. The process of measuring these deep (500-2000 m.) temperatures is both costly and time-consuming, and were it possible to estimate the position of the deep temperature gradients from the surface gradient, some aspects of Gulf Stream surveying would be vastly simplified. Even so, the relatively slow speeds of the ships normally used for taking ocean temperatures plus the possible local shifting of the Stream during the time necessary for a crossing could introduce errors.

The recent development of the Stommel-Parson air-borne radiation thermometer does much to solve these problems. A detailed description of this instrument is beyond the scope of this report, but briefly it is an infrared radiation detector installed in an airplane. Through a simple optical system it looks alternately (10 cycles/sec.) at the surface of the ocean directly beneath the plane and at a vessel of water in the instrument itself, recording the difference in temperature between the sea surface and this reference black body. The operator changes the temperature of the reference body until the temperature difference noted by the instrument is zero. Atmospheric vapor absorption can lead to absolute temperature errors as great as 3-4°F., but produces only negligible errors in the gradient structure. Relative temperature changes are noted instantly and accurately. A complete description of this instrument will be published, but even from this sketchy treatment it will be seen that the air-borne radiation thermometer enables the oceanographer to make rapid sections of the surface thermal pattern.

The data obtained from nearly 100 ship crossings of Gulf Stream water have been summarized in an effort to see what may be inferred about deep water temperature gradients from the surface gradients. If reliable and consistent correlation be found, the way lies open for rapid charting of the Gulf Stream from the air.

The graphs presented at the end of this report plot the temperatures at specified depths against the distance run by the ship. Because of the relatively late introduction of the 900-foot bathythermograph (BT), two-thirds of the graphs prepared plot only the surface and 100 m. temperatures. Continuous series of 200 m. temperatures were not available from some cruises, hence the deepest temperature consistently reported has been plotted.

In this paper the term "warm core" is used to designate that water in the Gulf Stream where the temperature is greater than that of the water at the same depth to the right, facing downstream.

The "edge of the Stream" will remain undefined, but will be used as a convenient term for "the neighborhood of the place where the horizontal pressure gradient goes to zero." The materials used were the profiles in Iselin's papers of 1936 and 1940, and the BT records on file at the Woods Hole Oceanographic Institution. Finally, the Fahrenheit scale of temperature is used throughout this report.

It would have been ideal to compare the surface and deep temperatures directly, but unfortunately the data were not suitable for this. The 10-mile station interval of the best hydrographic crossings of the Stream is

> "far too wide to disclose many significant details in the temperature distribution at depths shallower than 100 m." (Iselin)

Thus it was necessary first to compare the deep temperature gradients with those at 200 m. from Iselin's data, and then to compare the latter with the 100 m. and surface gradients from the BT data.

The profiles in Iselin's paper show that the 200 m. temperature variations reflect those in deeper (down to 2000 m.) water, especially on the left-hand edge of the Stream. On the right-hand edge, however, the 200 m. temperature often has a short steep gradient (the right-hand edge of the warm core), while the deeper temperatures remain comparatively steady. The 100 m. temperature variations follow those at 200 m. in the vicinity of the warm core, although the 100 m. temperature change on the right-hand side is often considerably greater (5-10°F.) than that at 200 m. In the slope water the situation is more confused, but even here the BT data show only one instance where the 100 m. change does not reflect a corresponding change at 200 m. Thus it will be seen that taking the 100 m. temperature as representative of the deep temperatures will not introduce a serious error. Comparisons of 100 m. and, where possible, 200 m. changes with surface temperature changes show that in 99 crossings of the Stream, only 17 times did the surface temperature fail to reflect markedly the deeper changes. Here seasonal variations must be considered, for each of the 17 instances cited above occurred between May and October.

In order to obtain a picture of these seasonal variations, the average winter and summer temperature changes at the left-hand side of the Gulf Stream have been computed. The results show that the 100 m. and 200 m. changes remain fairly constant throughout the year, and at these depths the Stream is 12-20° warmer than slope water at the same depth. At the surface, however, seasonal effects are pronounced. In winter, the surface temperatures show the Gulf Stream to be 15-20° warmer than the

slope water, but in summer the increase in temperature is only about 5-10°. Indeed, sometimes no surface distinction between Stream and slope water can be found during the summer months.

	Oct.-Apr.	May-Sep.
Surface	17°	8°
100 m.	14.5°	17°
200 m.	13°	15°

Table 1: Average temperature differences between the Gulf Stream water and slope water at the same depth.

Moreover, the ratio of 100 m. and 200 m. temperature changes to the surface temperature change have been computed for each crossing (Table 2). This comparison can only be interpreted qualitatively, but it does show that the best months for using the surface temperature gradients as Gulf Stream indicators are November through May.

	100 m. T. Delta / Surface T. Delta	200 m. T. Delta / Surface T. Delta
Jan.	0.9	1.0
Feb.	1.1	0.8
Mar.	1.1	-
Apr.	0.6*	-
May	1.1	1.1
Jun.	1.9	1.7
Jul.	2.2	1.9
Aug.	3.1	2.7
Sep.	3.5	3.5
Oct.	2.4	2.6
Nov.	1.2	-
Dec.	1.0	-

Table 2: Ratios of temperature differences at the surface, at 100 m., and at 200 m. between Gulf Stream and slope water.

* Based on one cruise which probably did not go completely across the Stream.

A most important measurement is that of the horizontal distance between the steep surface temperature gradient associated with the Gulf Stream and the temperature gradient at 100 m. or 200 m. A knowledge of this could indicate the structure of the

"front" which is the Gulf Stream, and show how well the position of the surface temperature change reflects the position of the Stream. The reference point chosen for the measurement of this distance was the start of the pronounced temperature gradient, for this point--or rather, region--can be located within 5 miles on each temperature curve. A difficulty with these measurements of distance is that at sea there is no way of determining when the ship's course is at right angles to the Stream. Hence the distances between the beginnings of the temperature gradients have been grouped in fairly large classes, for any smaller grouping would be misleading.

In the vast majority of these cases the surface change preceded the deeper changes as the vessel entered the Stream.

	Surface temp. change shoreward of 100 m. change.			Surface temp. change seaward of 100 m. change.	
WINTER	(more than 15 mi.)	(15-5)	(5-0-5)	(5-15)	(more than 15 mi.)
Off Nova Scotia	-	-	6	2	-
Off New York	4	9	8	-	-
Off Cape Hatteras	1	5	7	-	-
SUMMER					
Off N.S.	4	12	10	-	3
Off N.Y.	4	12	9	1	-
Off C.H.	-	4	6	-	-

Table 3: Distances between the surface and deeper temperature gradients at left-hand side of the Gulf Stream.

Summarizing these results qualitatively, we can make the following classifications for using the surface temperature change as an indicator of the Gulf Stream:

Good Indicator:

A sharp surface temperature change, much greater than the slope water fluctuations, which is within 10 miles of the 100 m. temperature change. (e.g., 3-4 Mar. 1946).

Fair Indicator:

(1) A noticeable surface change, but more nearly of the order of the slope water fluctuations (7-9 Jul. 1949, or
(2) A good surface change more than ten miles from the 100 m. change (13-14 Jul. 1941).

Poor Indicator:

No distinguishable surface change corresponding to a change at 100 m. (9-12 Aug. 1949).

Breaking down the total number of crossings by months produces Table 4.

	Good	Fair	Poor
Jan.	4	-	-
Feb.	2	-	-
Mar.	2	1	-
Apr.	6	-	-
May	18	1	2
Jun.	23	2	4
Jul.	1	1	1
Aug.	5	4	4
Sep.	3	1	3
Oct.	1	1	1
Nov.	2	-	-
Dec.	3	2	-

Table 4: Surface gradient indicators of Gulf Stream position.

Of the 99 crossings, 71 give good surface indications of the position of the Stream, 13 are fair, and 15 poor.

On the right-hand side of the warm core is a much smaller, but still pronounced, change in temperature, averaging 5° at the surface and at 100 m., and still noticeable at 200 m. (2.5°). In 24 cases the surface change is to the right of the 100 m. change, in 6 cases it is to the left, and in 11 cases the temperature changes are too small or confused to be interpreted

with any accuracy. The remainder of the crossings did not get completely through the right-hand side of the warm core, hence no comparison is possible.

In order to gain some idea of the form of the warm core, the cases in which the surface temperature changes on both sides of the core occurred more than 15 miles from the 100 m. changes have been compared. In 7 cases the warm core is wider at the surface than at 100 or 200 m. (Fig 1a), but one inversion was found (1b). In 3 cases the warm core takes the shape of a parallelogram slanting downward to the right (1c), and in one instance the direction of the slant is reversed (1d).

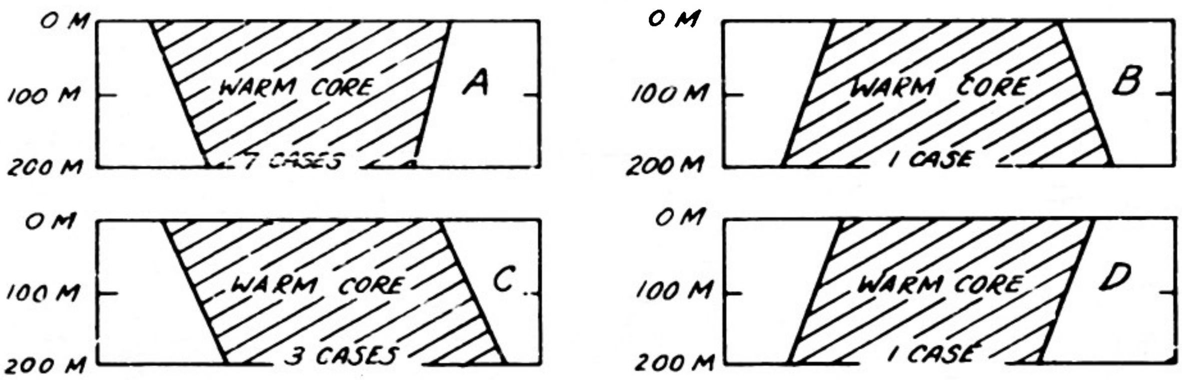

FIGURE 1

In the slope water the temperature gradients become irregular and confused. The most consistent change in this region is a short steep gradient near the 100-fathom curve. There may occasionally be a surface change and no corresponding 100 m. change, or the reverse. In summer the surface gradient is a good indicator of deep temperature conditions 12 times, and a poor indicator 13 times. In winter, the surface change is a good indicator 5 times, and a poor one 9 times. This is unusual in that it apparently shows the summer surface gradient to be slightly more reliable as an indicator of deep temperature changes than the winter gradient, a reversal of the situation in the Gulf Stream proper. Because of the confused nature of this water, however, and the small size of the changes involved, the only conclusion which may be reached from the present data is that in the slope water the surface temperature gradient is a dubious indicator of deep changes.

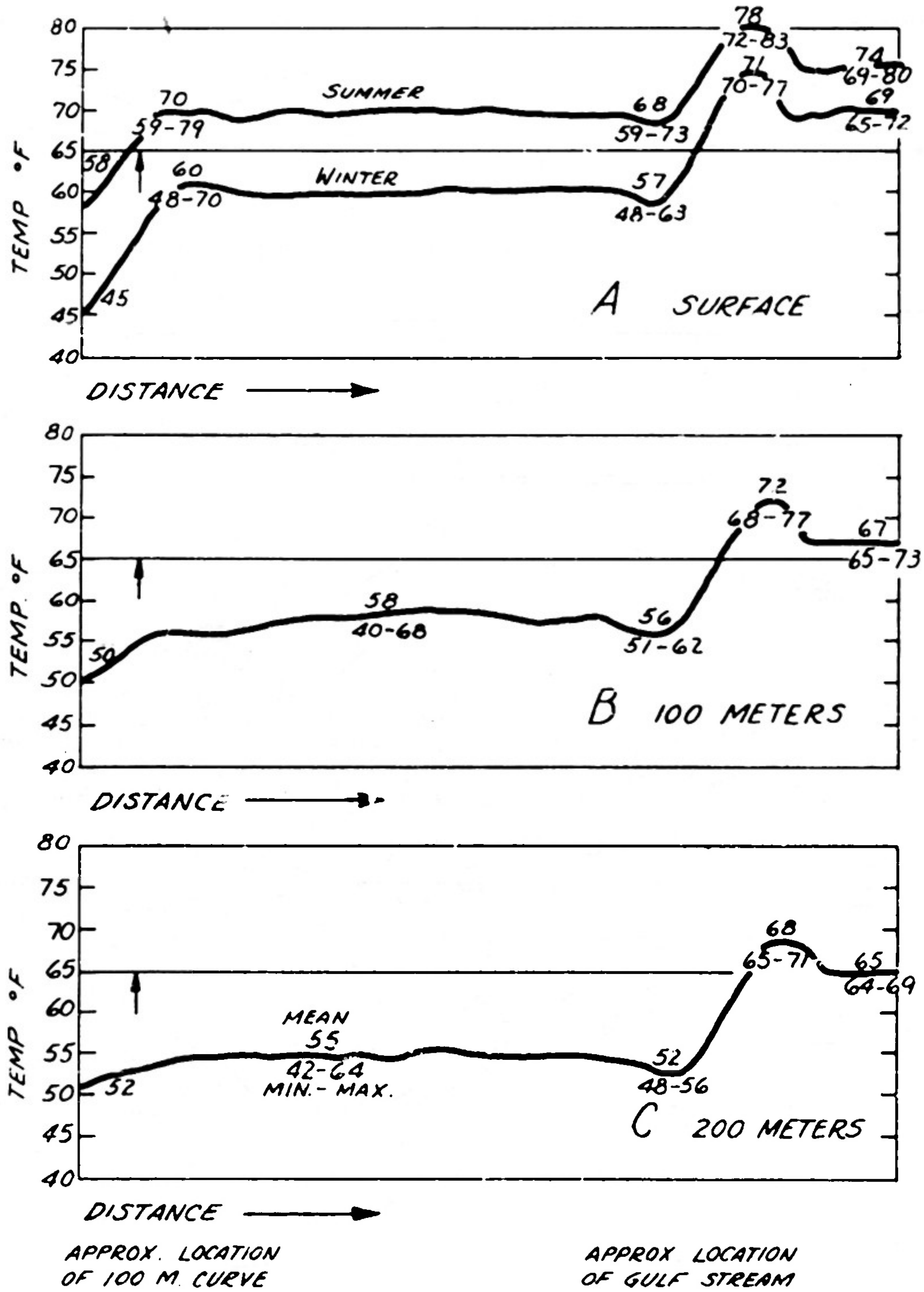

FIGURE 2 MEAN TEMPERATURE-DISTANCE CURVES

In order to investigate any permanent or semi-permanent features in the temperature structures of Gulf Stream and slope water, the temperature graphs have been averaged and the resultant surface, 100 m., and 200 m. curves drawn (Fig. 2). Since the distance from the 100-fathom curve to the Gulf Stream varies, a flexible horizontal scale is used, with the absolute distance between these two points being stretched or compressed into a standard length. Furthermore, since some of the observations were made off Nova Scotia and some off New York*, the absolute temperatures vary markedly, but the gradients show a consistent pattern. The surface temperature graph has been drawn to show the distinct summer and winter patterns, but since the seasonal fluctuations average only 1-2° at 100 m., and are insignificant at 200 m., one curve will suffice for the entire year.

Proceeding from the continental shelf, as shown in the diagrams, there is a sharp increase in temperature at the surface and at 100 m. in the neighborhood of the 100-fathom curve, followed by a steady increase at all depths to a region of maximum temperature in the slope water. There is then a slight cooling, followed by the abrupt rise of temperature at the left-hand side of the Stream. Beyond the warm core there is a marked cooling at depths to 200 m., and then the water maintains a steady temperature out into the Sargasso Sea.

It is interesting to compare these data with those obtained by Church from many surface thermograph records across the western North Atlantic. Church noted the presence of

> "...a very abrupt break in the temperature between the coastal and slope waters at the edge of the continental shelf south of Georges Bank."

The present data confirm this break, and show it to be noticeable even at 100 m. Church's records also show a narrow (1-2 mi.) cold zone on the left-hand edge of the warm core. The graphs in this report show this cool zone to be wider, although the discrepancy may perhaps be ascribed to different methods of obtaining and processing the data. In other respects, agreement between the two sets of surface data is very good.

Summary

1. The surface, 100 m., and, where possible, 200 m. temperatures from 99 BT sections across or well into the Gulf Stream have been

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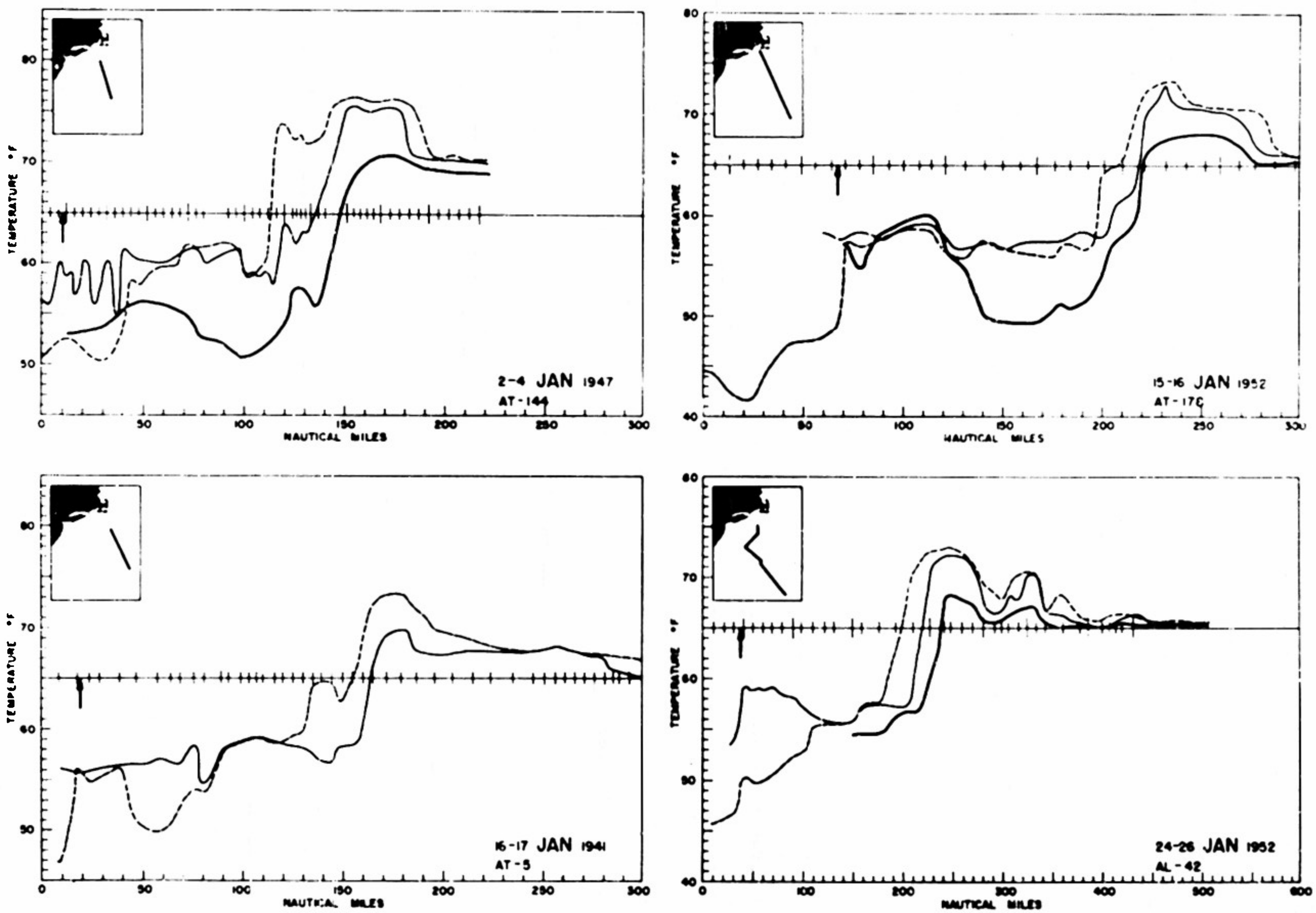
* Data obtained off Hatteras, where the Gulf Stream flows very near the continental shelf, have not been considered in this process.

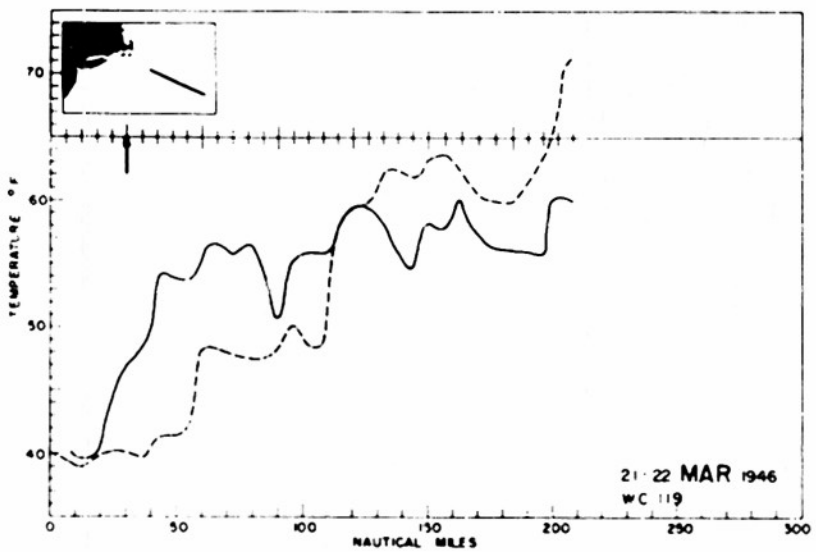
compared, with the object of investigating the possibility of determining the position of the Gulf Stream from an examination of surface temperatures alone. The results show that for the main current of the Stream, there is good agreement between surface and deep temperature gradients during the period from November to May. This must be further qualified, since observations on the right-hand side of the Gulf Stream are rather widely spaced and less consistent than those on the left. Thus, for a dependable indication of the position of the Gulf Stream by surface gradients, the area must be restricted to the left-hand edge of the Stream, and the season to the winter months.

2. At no season of the year do surface temperature gradients in the slope water inshore of the Gulf Stream reliably reflect those in deep water.

3. The picture of the surface thermal pattern outlined above (p. 7) agrees with and is well supported by Church's earlier data.



2-4 JAN 1947
AT-144
15-16 JAN 1952
AT-17C
16-17 JAN 1941
AT-5
24-26 JAN 1952
AL-42
TEMPERATURE °F
NAUTICAL MILES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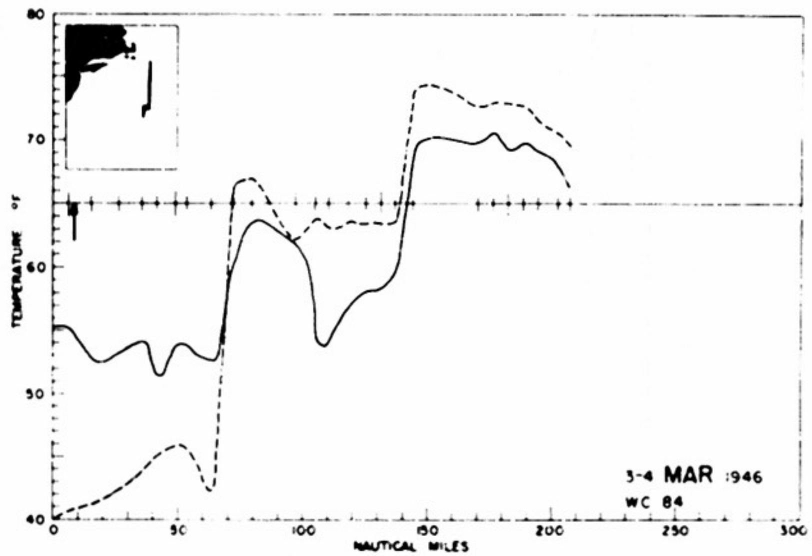
WC 119
TEMPERATURE °F
NAUTICAL MILES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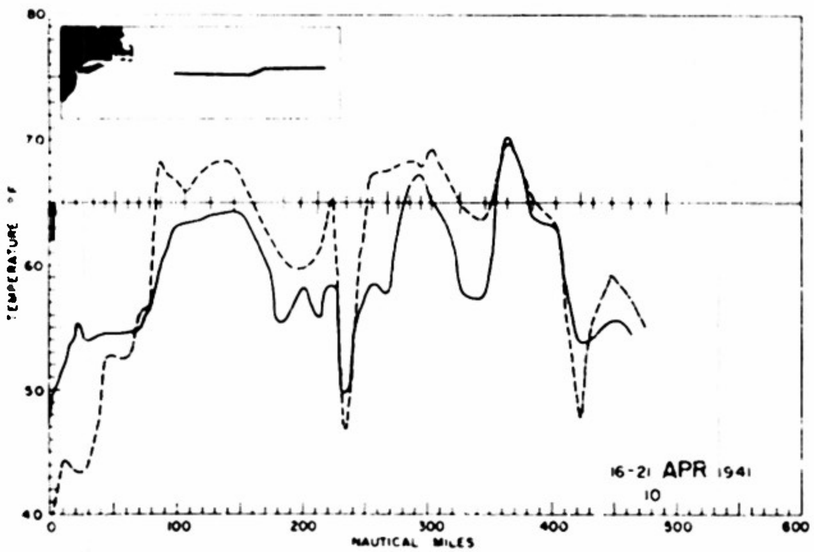
WC 84
TEMPERATURE °F
NAUTICAL MILES


16-21 APR 1941
10
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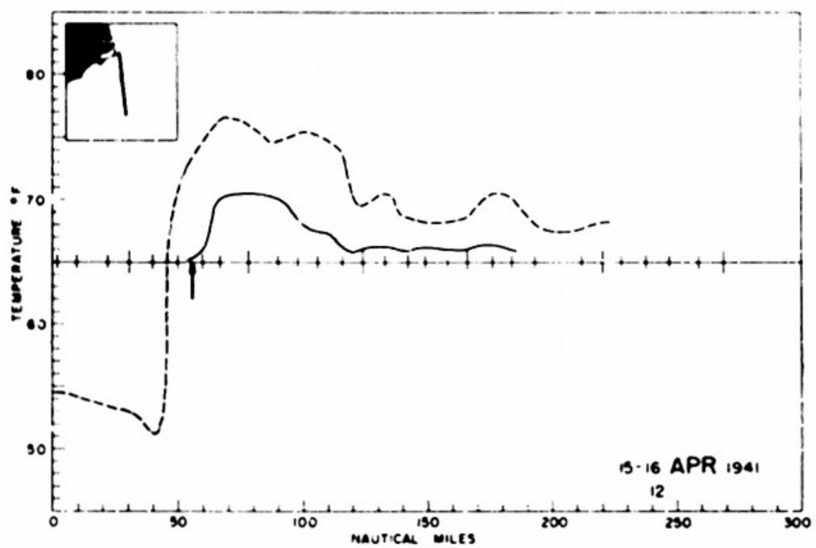
NAUTICAL MILES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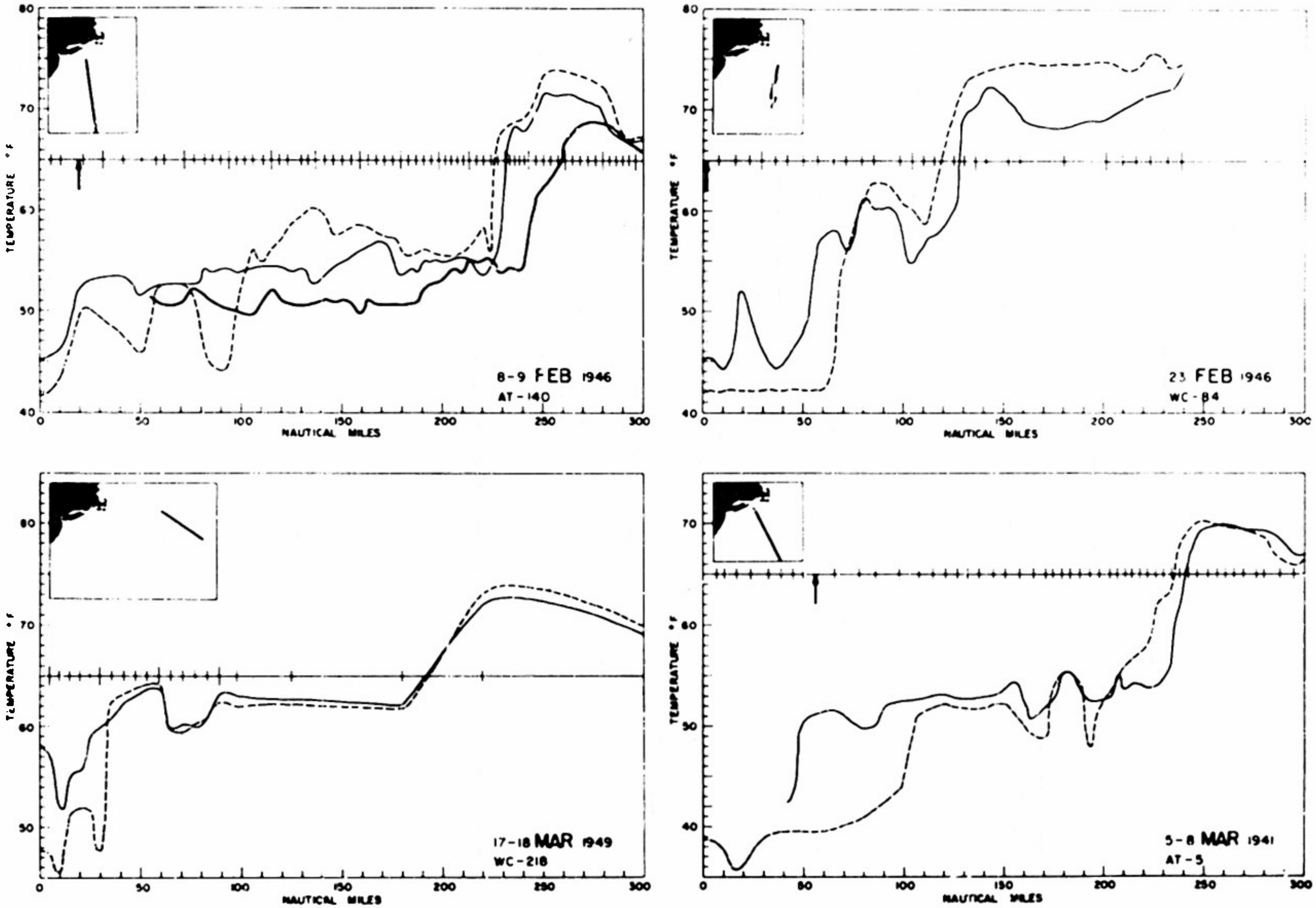
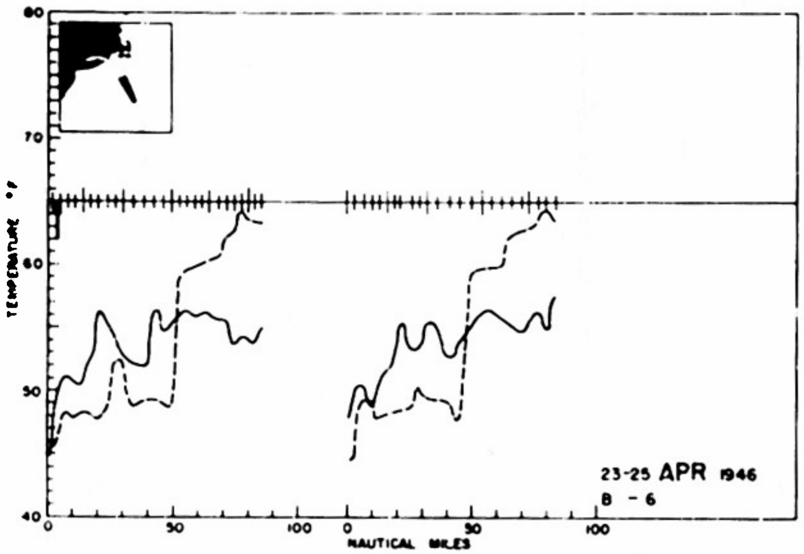
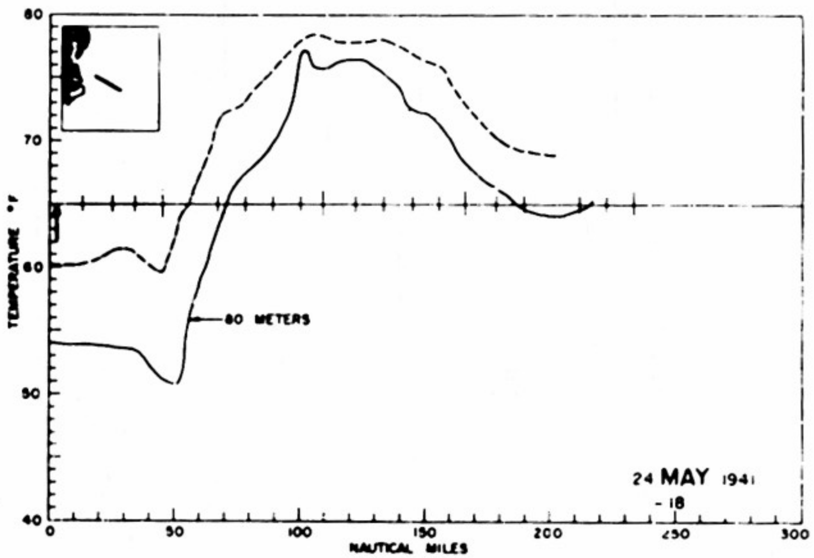
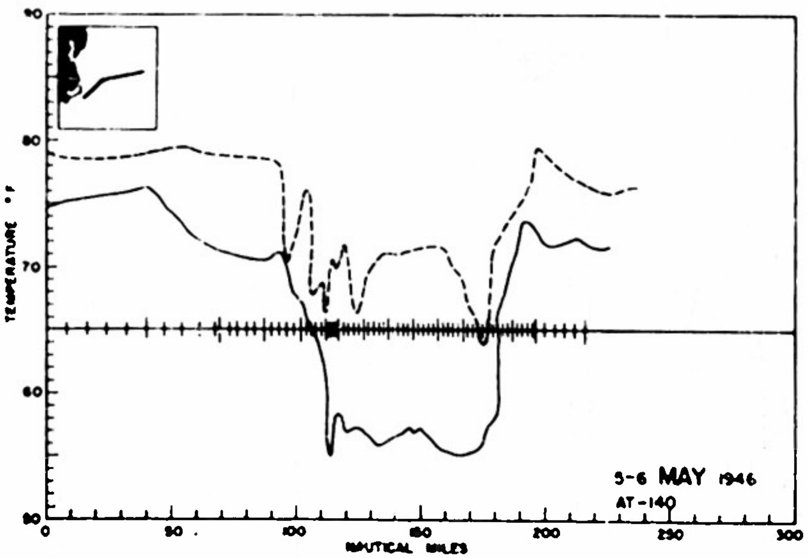
12
TEMPERATURE °F
NAUTICAL MILES


8-9 FEB 1946
AT-140
23 FEB 1946
WC-84
17-18 MAR 1949
WC-218
5-8 MAR 1941
AT-5
TEMPERATURE °F
NAUTICAL MILES


TEMPERATURE °F
NAUTICAL MILES
23-25 APR 1946
B - 6


TEMPERATURE °F
NAUTICAL MILES
80 METERS
24 MAY 1941
- 18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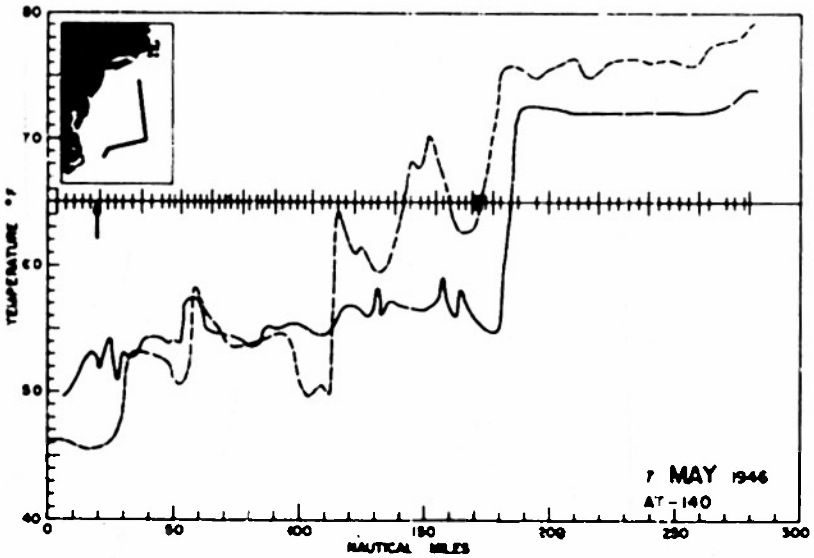
AT-140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7 MAY 1946
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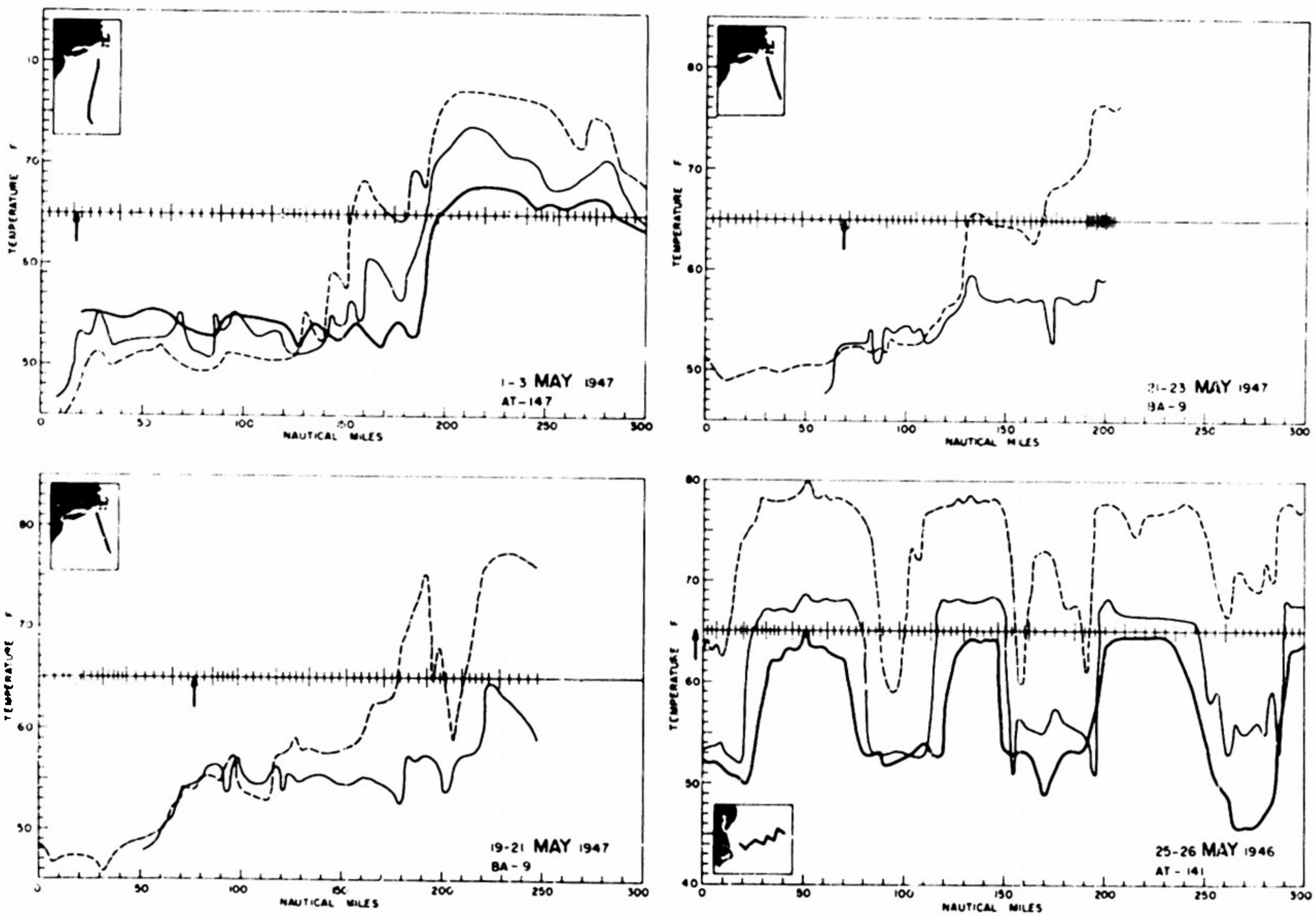
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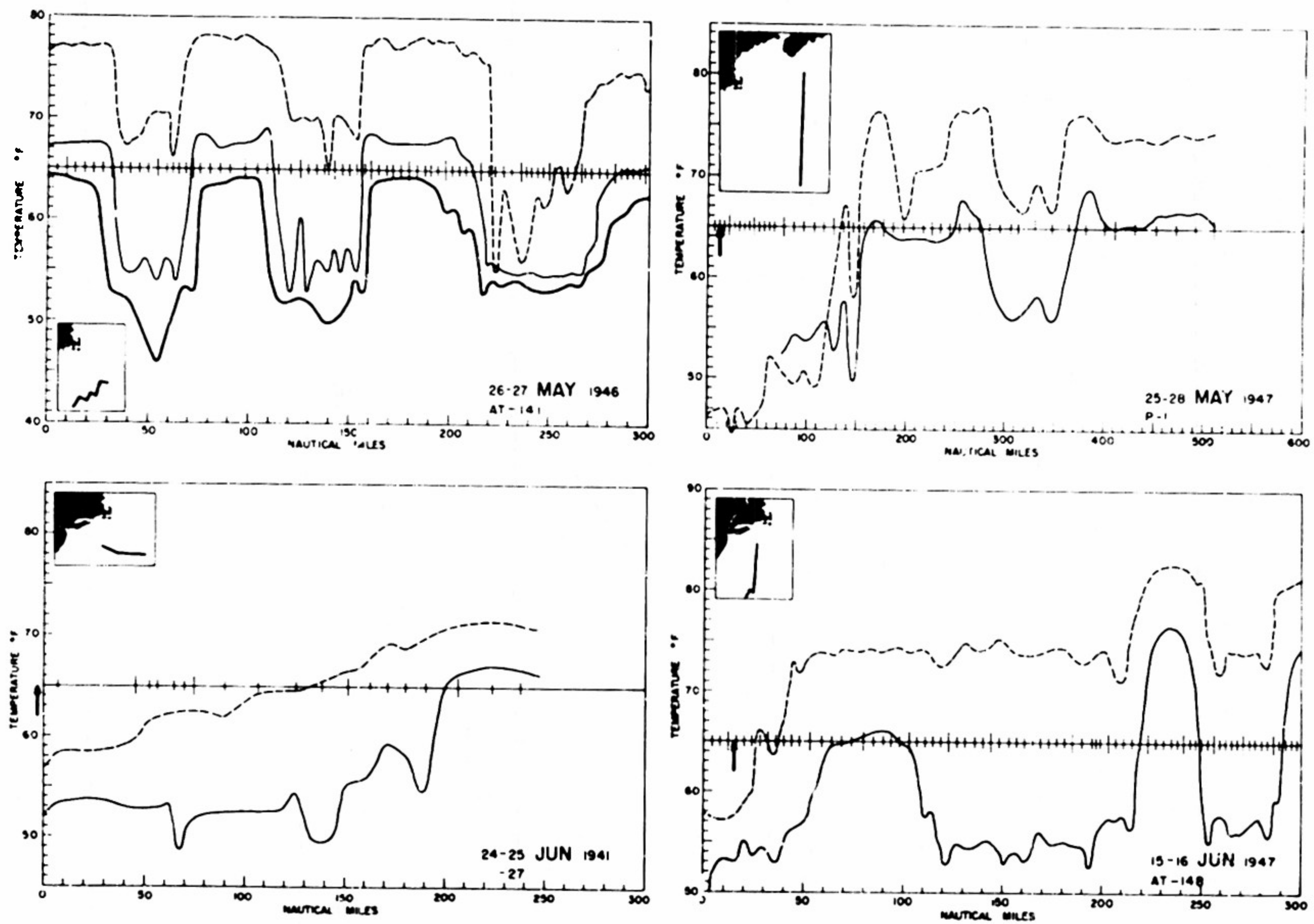
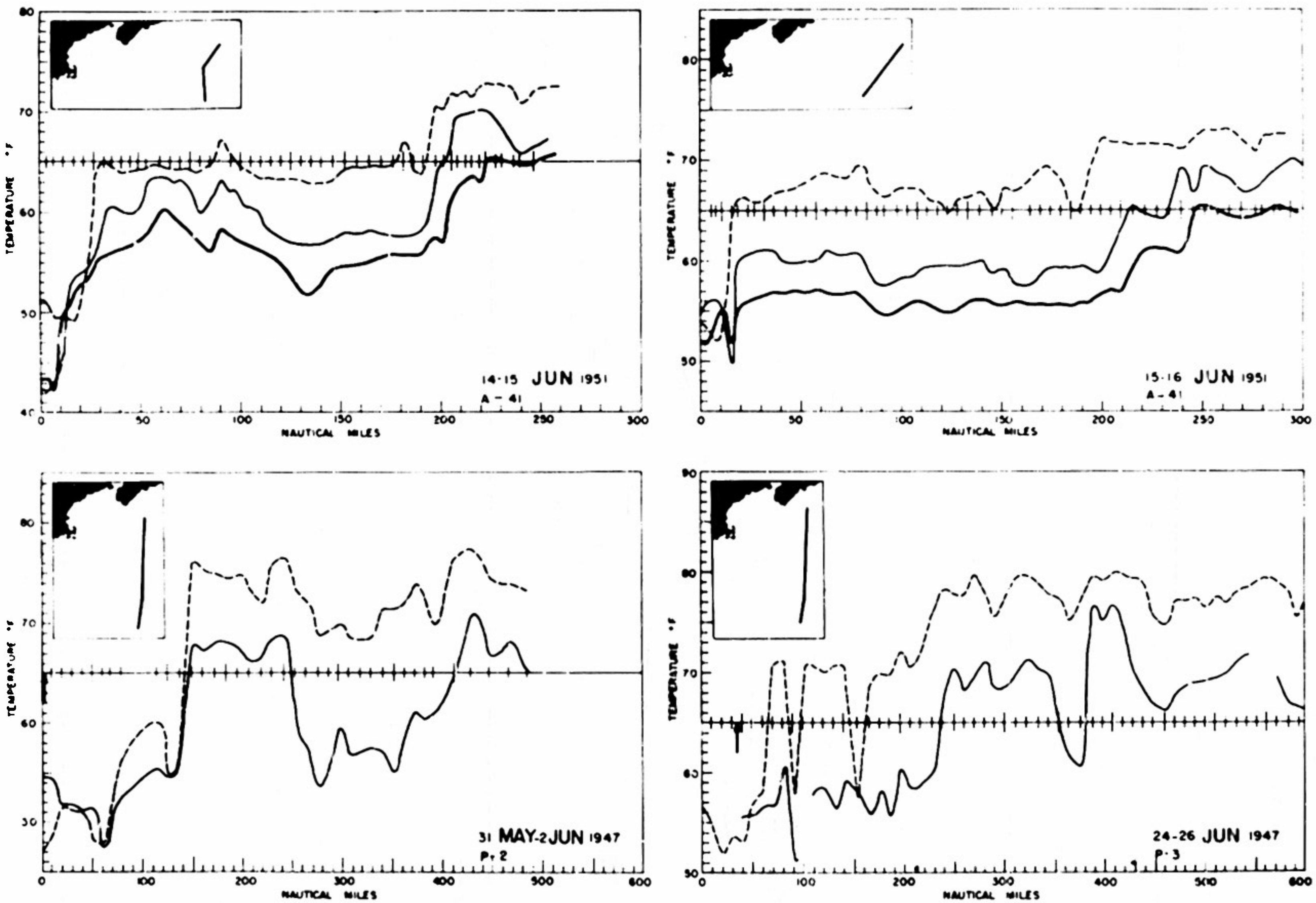
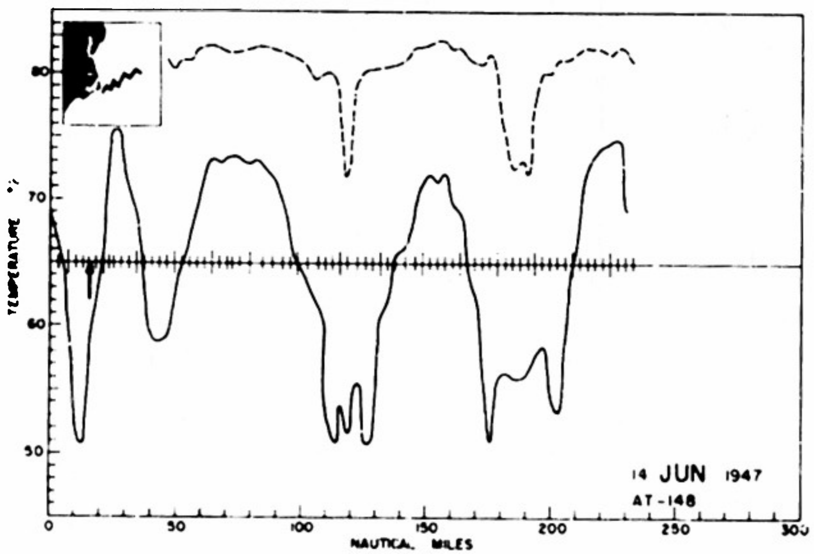
21-23 MAY 1947
BA-9
19-21 MAY 1947
BA-9
25-26 MAY 1946
AT-141
TEMPERATURE F
NAUTICAL MILES



26-27 MAY 1946
AT-141
25-28 MAY 1947
P-1
24-25 JUN 1941
-27
15-16 JUN 1947
AT-148
TEMPERATURE °F
NAUTICAL MILES


14-15 JUN 1951
A - 41
15-16 JUN 1951
A - 41
31 MAY-2 JUN 1947
P-2
24-26 JUN 1947
P-3
TEMPERATURE °F
NAUTICAL MILES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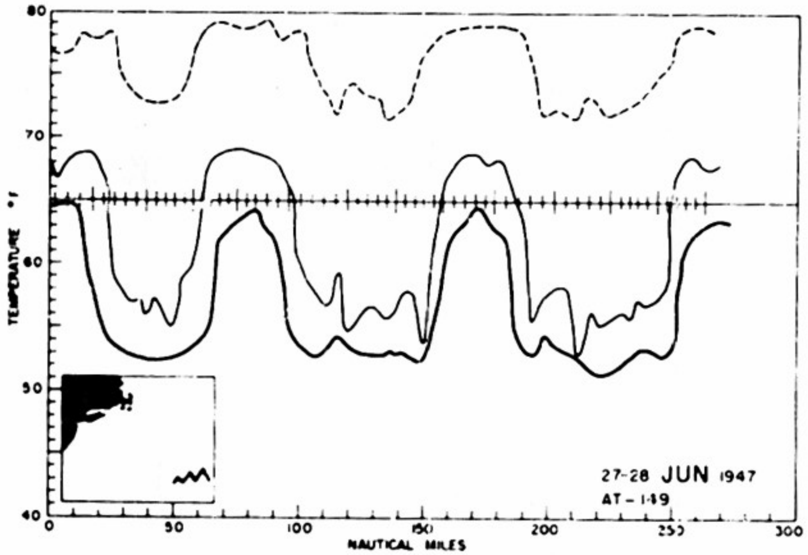
TEMPERATURE °F
NAUTICAL MILES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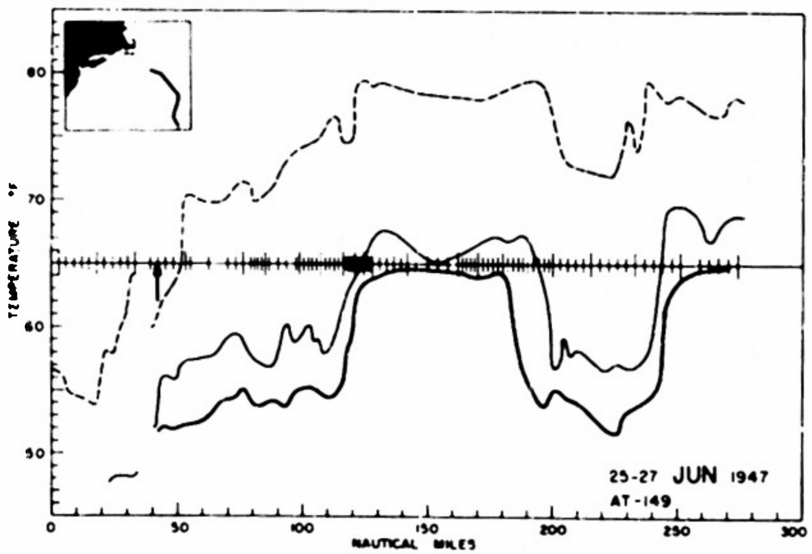
TEMPERATURE °F
NAUTICAL MILES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TEMPERATURE °F
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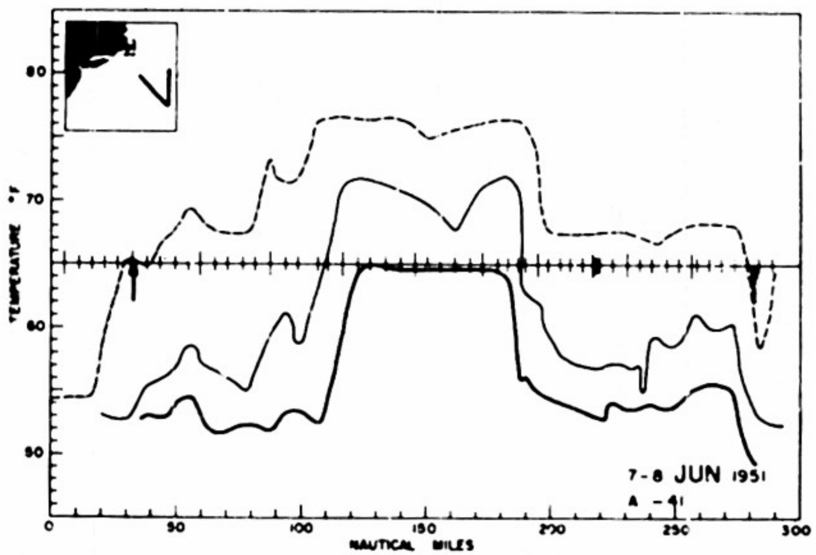
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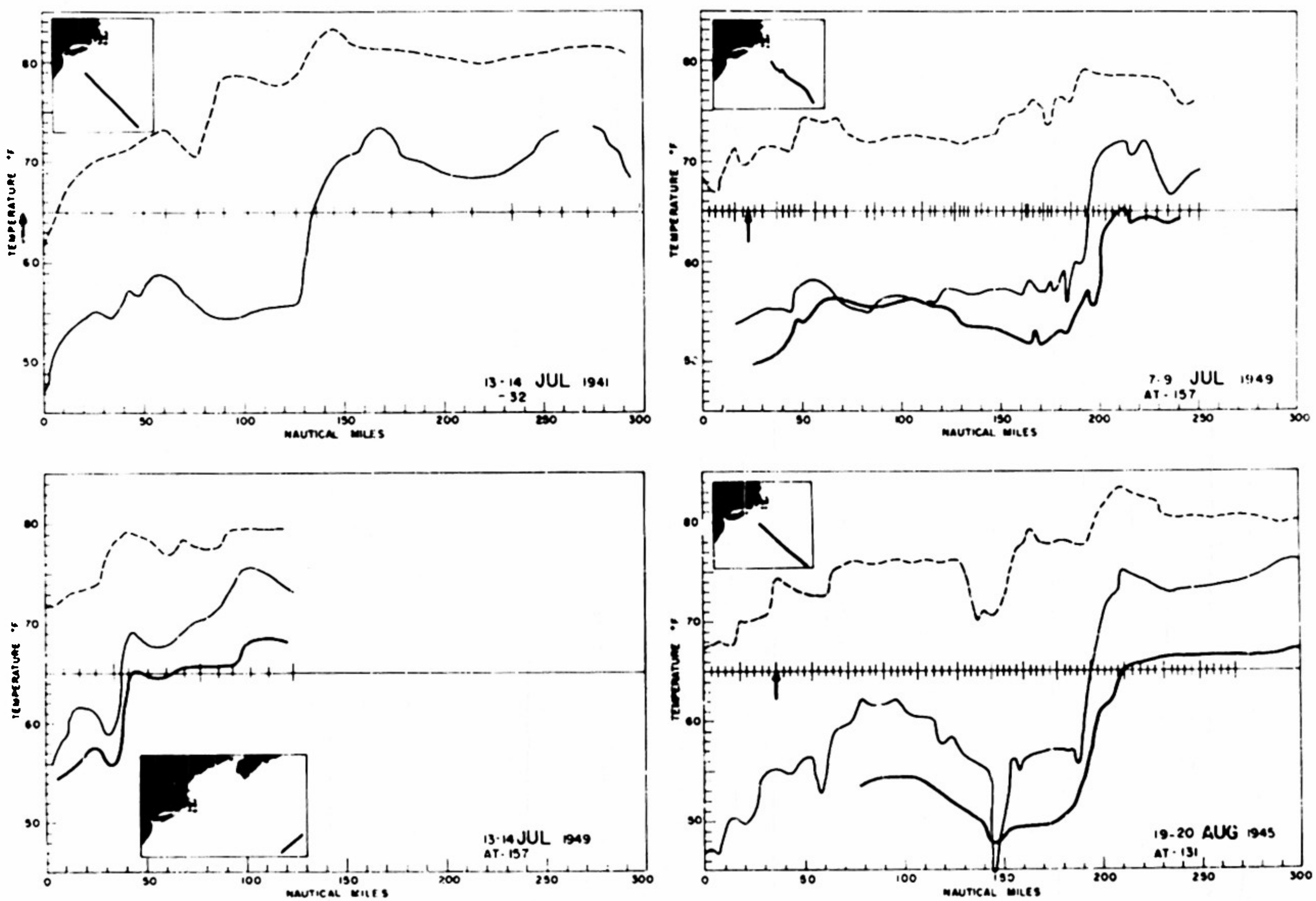
A-41
TEMPERATURE °F
NAUTICAL MILES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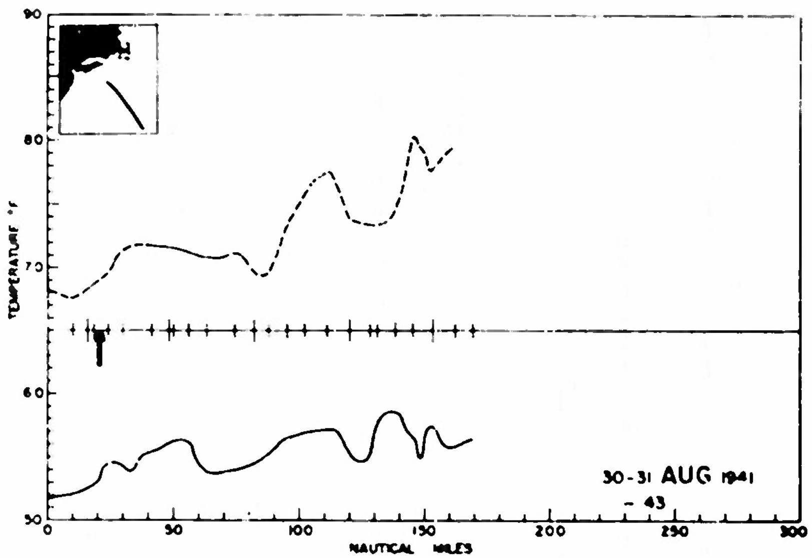
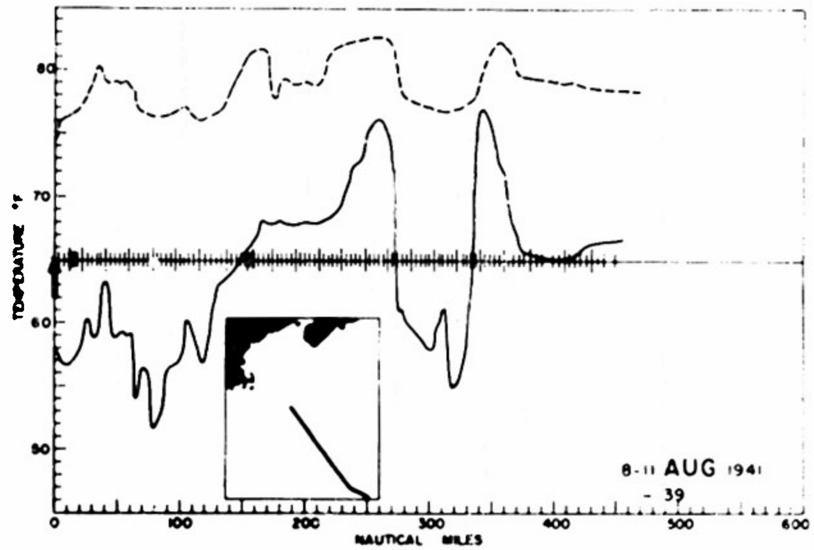
-32
7-9 JUL 1949
AT-157
13-14 JUL 1949
AT-157
19-20 AUG 1945
AT-131
TEMPERATURE °F
NAUTICAL MILES



TEMPERATURE °F
30-31 AUG 1941
- 43
NAUTICAL MILES



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8-11 AUG 1941
- 39
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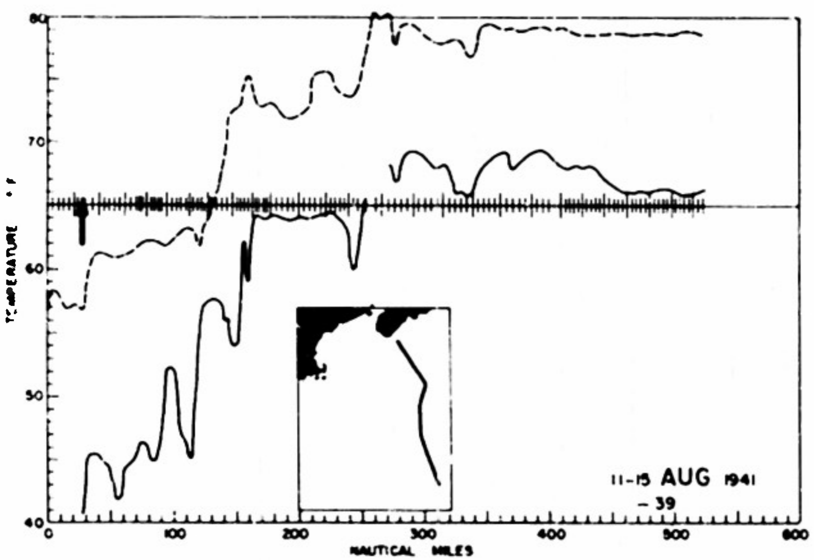

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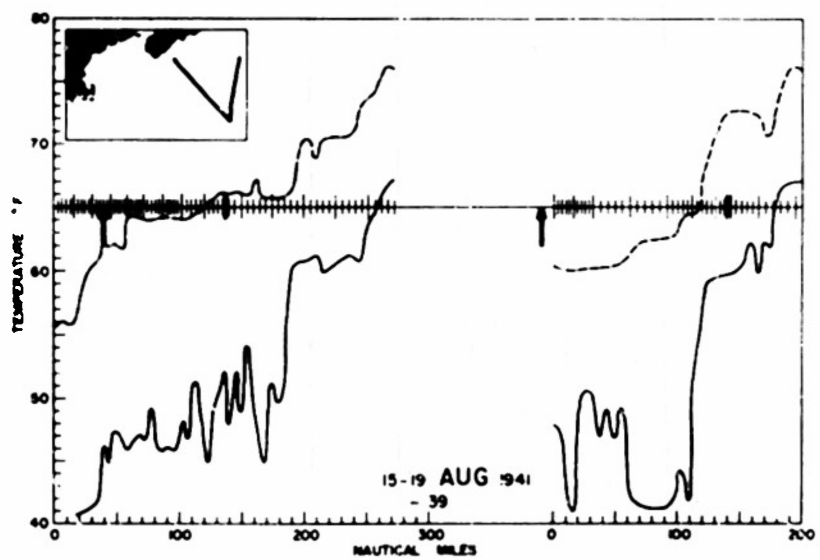

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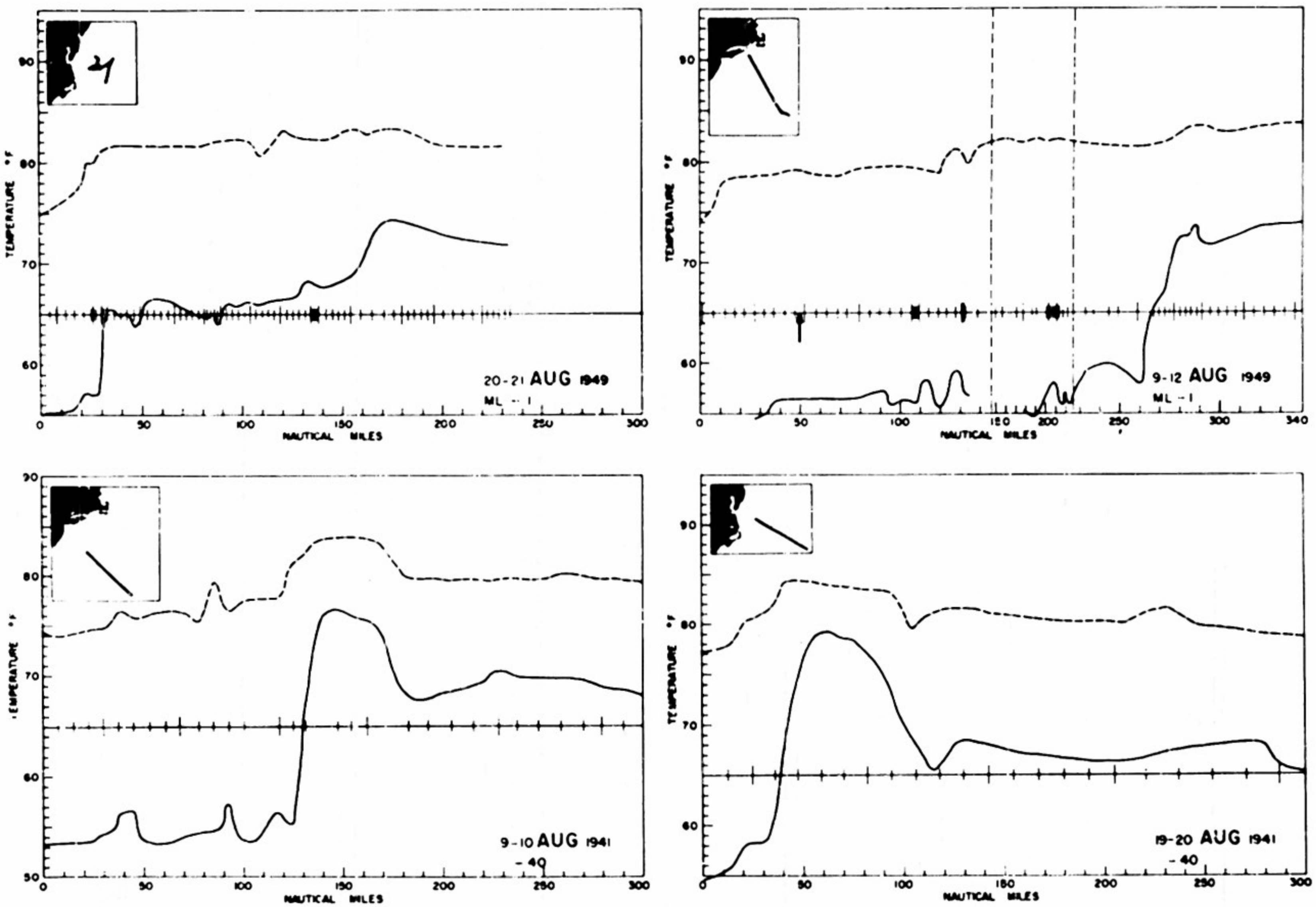
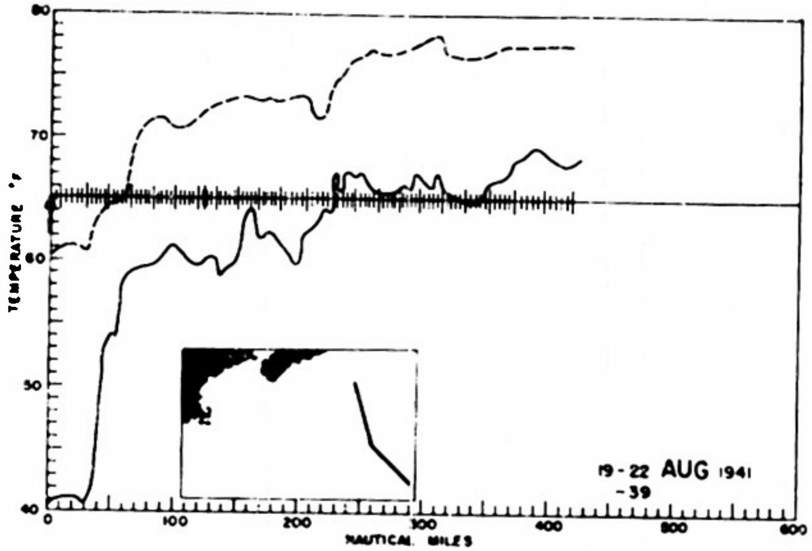


20-21 AUG 1949
ML - 1
9-12 AUG 1949
ML - 1
9-10 AUG 1941
- 40
19-20 AUG 1941
- 40
TEMPERATURE °F
NAUTICAL MILES



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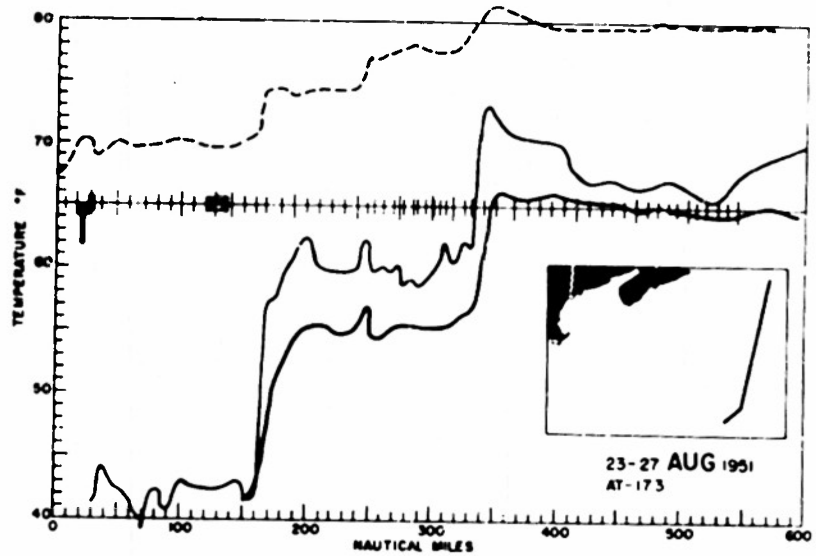
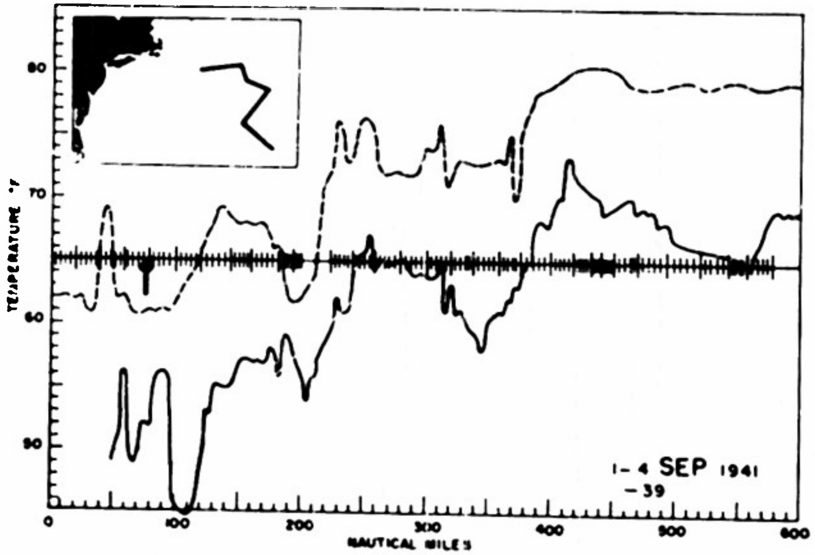
TEMPERATURE °F
NAUTICAL MILES



23-27 AUG 1951
AT-173
TEMPERATURE °F
NAUTICAL MILES



1-4 SEP 1941
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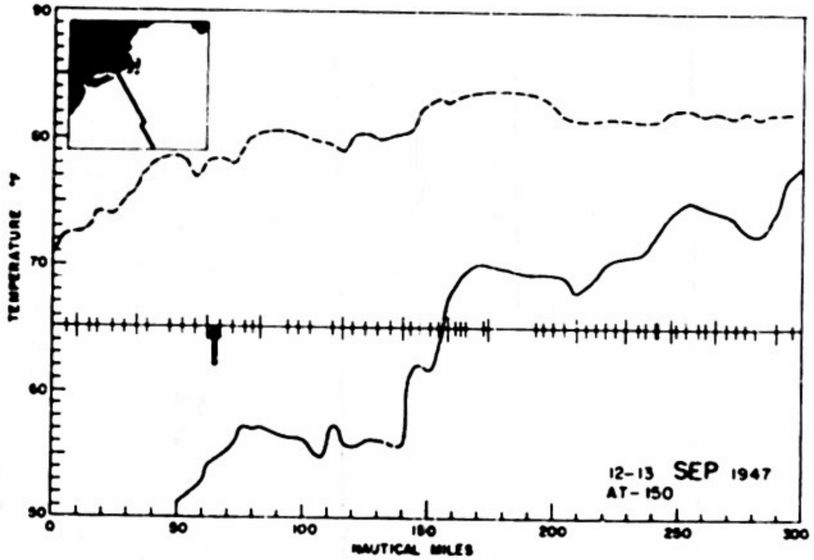
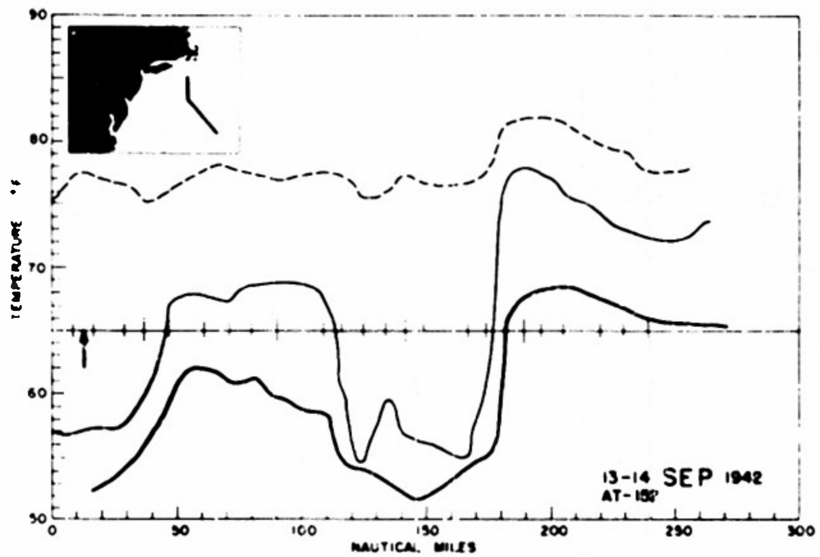
TEMPERATURE °F
NAUTICAL MILES



12-13 SEP 1947
AT-150
TEMPERATURE °F
NAUTICAL MILES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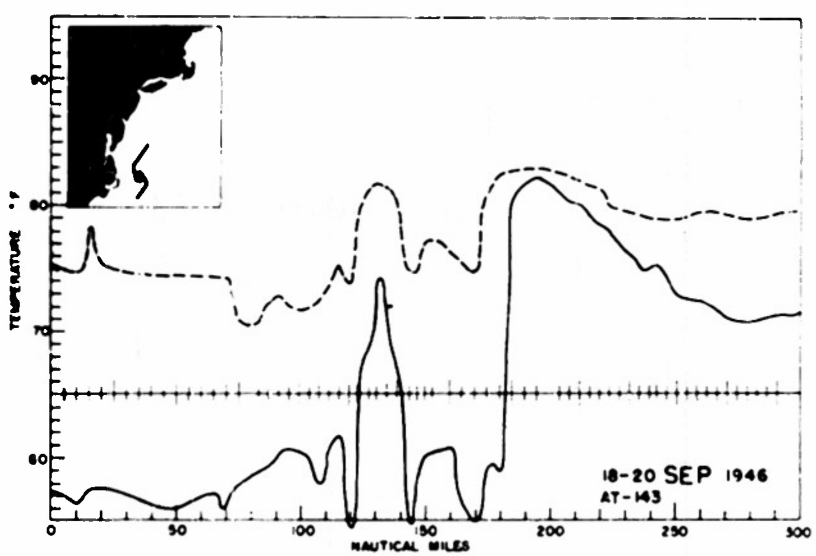
NAUTICAL MILES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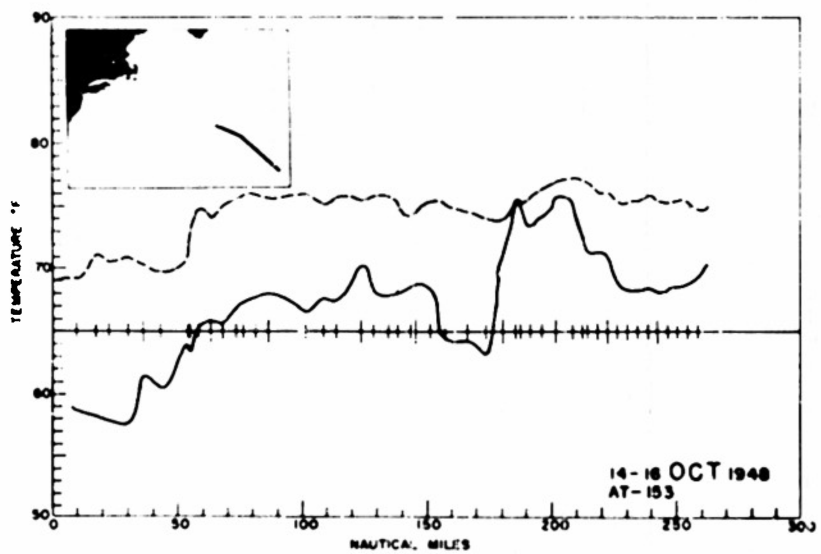
TEMPERATURE °F
NAUTICAL MILES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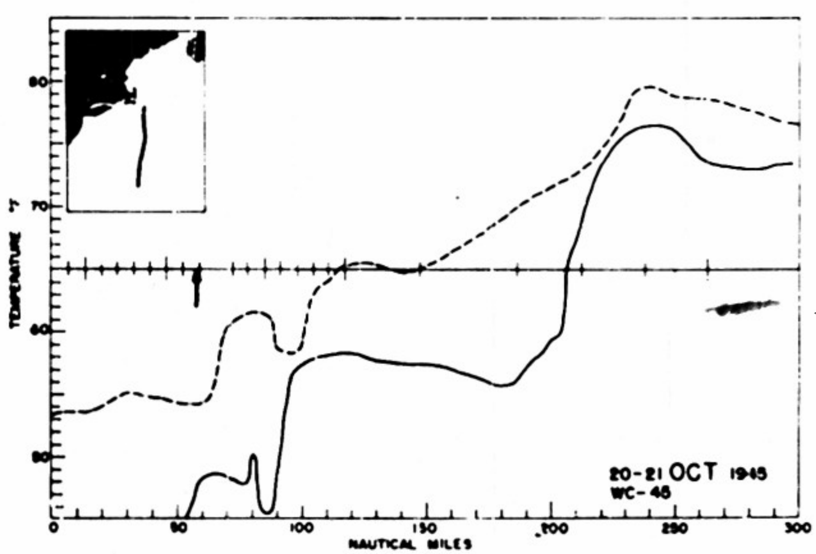
TEMPERATURE °F
NAUTICAL MILES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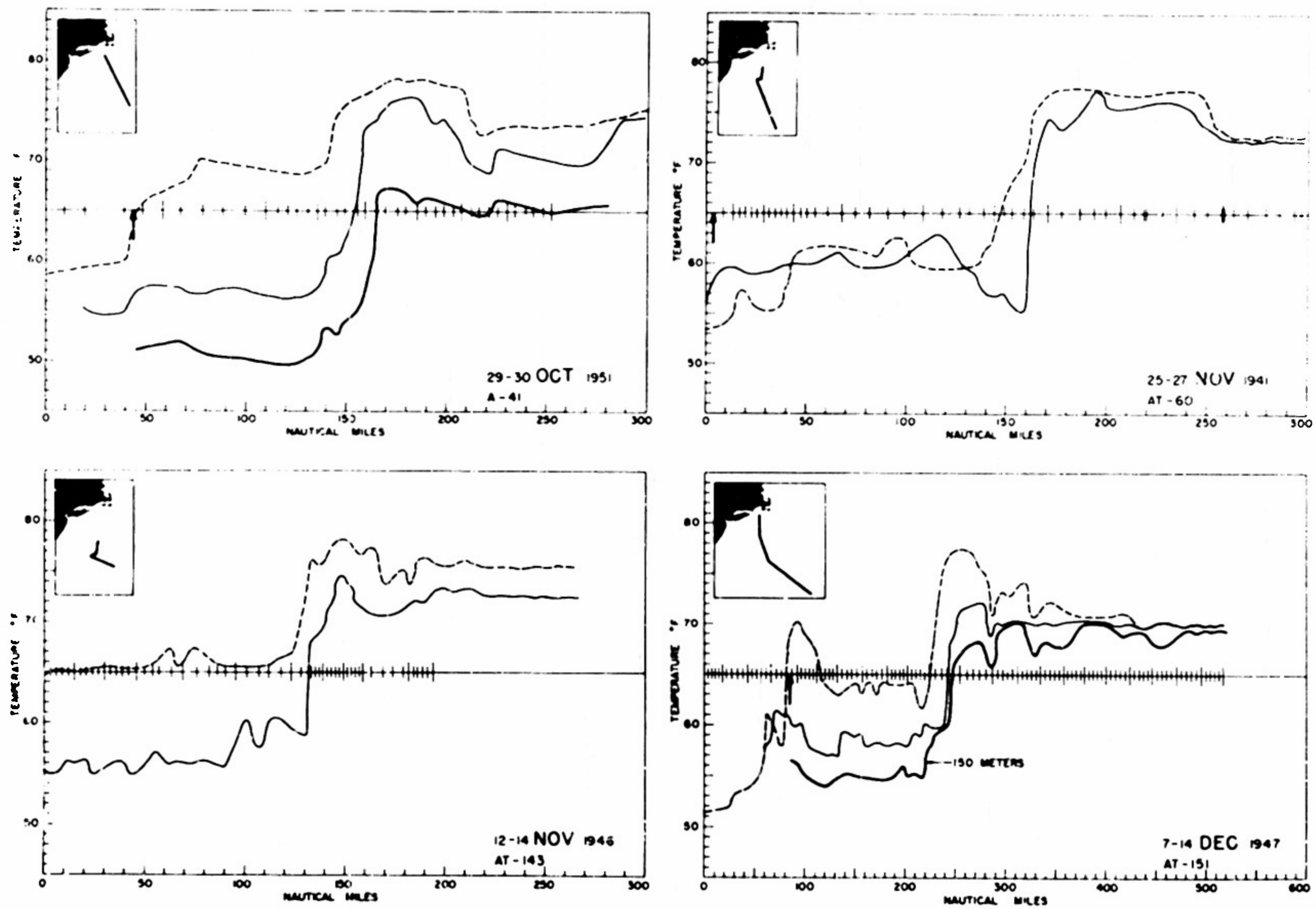
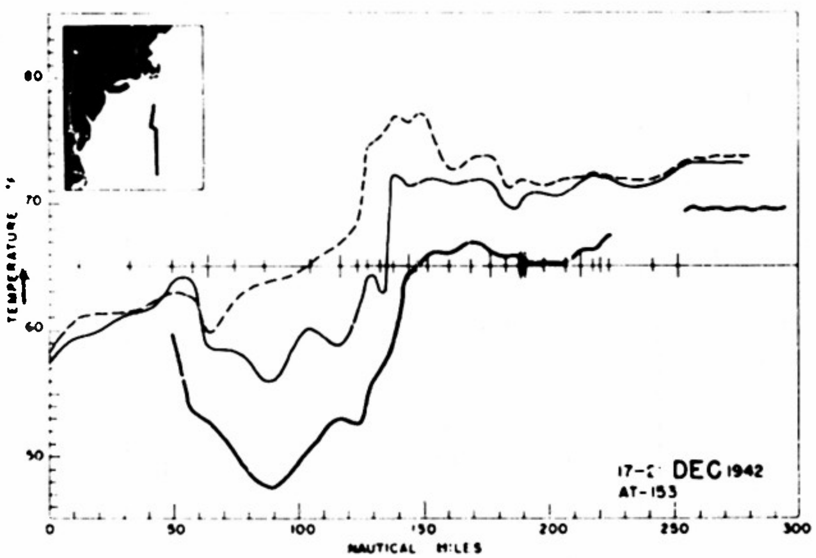
WC-46
TEMPERATURE °F
NAUTICAL MILES


29-30 OCT 1951
A-41
25-27 NOV 1941
AT-60
12-14 NOV 1946
AT-143
7-14 DEC 1947
AT-151
150 METERS
TEMPERATURE °F
NAUTICAL MILES



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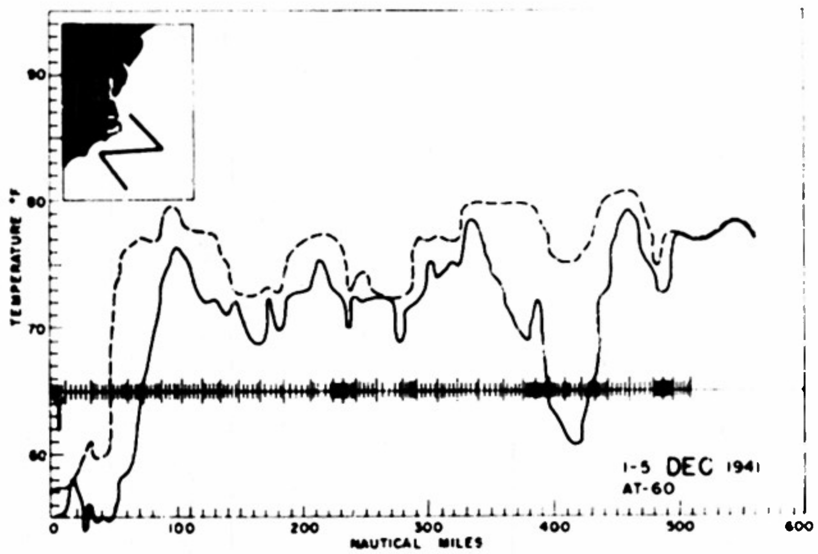
AT-153
TEMPERATURE °F
NAUTICAL MILES



1-5 DEC 1941
AT-60
TEMPERATURE °F
NAUTICAL MILES

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